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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.2-DN-B0105-02

PRELIMINARY ENTRY TRAJECTORY FOR 1ST ORBITAL FLIGHT TEST (OFT)

ENGINEERING SYSTEMS ANALYSIS

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This Design Note is submitted to NASA under Task Order B0105, Subtask (Integrated Entry Systems) in fulfillment of Contract NAS 9-13970.

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(NASA-CR-147766) PRELIMINARY ENTRY TRAJECTORY FOR 1ST ORBITAL FLIGHT TEST (OFT). SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT, ENGINEERING SYSTEMS ANALYSIS (McDonnell-Douglas Technical

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1.0 Summary

This design note presents a preliminary trajectory from entry interface to TAEM (Terminal Area Energy Management) interface for the 1st Orbital Flight Test (OFT) based on information in the Strawman (MFTAD) Master Flight Test Assignments Document Reference A. The enclosed point-mass trajectory may be utilized for preliminary purposes, meeting the requirements of this document. The trajectory was derived utilizing the January 1975 ADC (Analytic Drag Control) Guidance, the latest TPS (Thermal Protection Subsystem) model information from NASA ES and December 1974 Aerodynamics for a mid center-of-gravity location (66.25%ℓ_b).

This development work was conducted under Contract Number NAS 9-13970 Task Order B0105.

2.0 Introduction

The MFTAD provides several general requirements to be met in the six mission Orbital Flight Test program of the Space Shuttle system. Many detailed system and subsystem requirements are also contained in the FTR (Flight Test Requirements) document Reference B. In order to assure that the OFT test program can adequately meet all of these requirements, and/or define a need for change or addition, preliminary entry trajectories are being developed. These trajectories are intended to be used for preliminary system and subsystem analysis purposes and to provide an overview of what will be experienced during the program.

This design note presents the pertinent parameters for the First OFT mission. A brief outline of the procedures employed as well as graphical and tabular displays of the output from the GEMASS simulation are presented for the trajectory from Entry interface to TAEM interface.

3.0 Discussion

In order to obtain a viable entry trajectory for a given mission, realistic initial conditions are necessary for any simulations which may be conducted. Such conditions are not identified at this time and must be developed based upon the overall requirements of the mission. The requirements for this mission are tabulated in Table I and were extracted directly from the MFTAD (Reference A). The constraints utilized or resulting from this trajectory development are also presented for comparison purposes.

In developing the initial conditions at entry interface it was first necessary to obtain a realistic orbit. For this purpose, reference was made to NASA General Working Paper No. 10,009 (Reference C). The 120 nautical mile orbit was selected and the orbital insertion conditions were extracted for use as initial conditions for a simulation of the orbital path in the GEMASS program as run in an orbital mode. The output of this program was then used for establishing the orbital ground path (Figure 1) which agreed almost precisely with the reference. This orbital path, now available to necessary accuracy, was used for defining the cross range distance and providing the position (latitude and longitude) and velocity vector direction necessary for any point along the path from which an entry simulation was desired. The insertion conditions utilized for this development are presented in Table II.

In order to define the velocity vector magnitude and flight path angle at entry interface an orbital retro program was utilized employing several different values of impulse each of which yielded different values of velocity, flight path angle, and earth central angle traversed to the 400,000 foot interface altitude.

From these data, several sets of initial conditions were defined as possible conditions for entry simulations. The initial conditions used were then selected based upon the output from the 3 DOF (Degree-of-Freedom) GEMASS which yielded the results necessary to best meet the MFTAD and FTR requirements. Based upon the entry conditions selected, the orbit retrofire point was established based upon the earth central angle traversed. These deorbit conditions are also presented in Table II. The entry interface initial conditions which were selected and used for this preliminary analysis are included in Table II including target and other pertinent data.

The pertinent data set utilized for these simulations were:
(1) The December 1974 Aero data as adjusted to a MID C.G. position
(2) The January ADC guidance model (41.5/31.5) and
(3) The simplified TPS model (Reference D)

4.0 Results

The results of this preliminary trajectory development are presented in Table III and Figures 2-18. Table III itemizes the pertinent maximum values of heating rate, heat load, temperatures at critical locations, normal load factor and the TAEM intercept conditions. Similar values for Baseline Mission 14414.1 (Reference E) are presented for comparison purposes and demonstrate the benign nature of the developed trajectory for the 1st OFT. As can be seen the temperatures on the body flap and elevon are less than 2230 degrees.

Figure 2 presents the final ground path up to a point just past TAEM intercept overlaid on a map of the California area including Edwards Air Force Base. Figures 3, 4, and 5 present angle of attack, bank angle, elevon deflection and body flap deflection schedule as a function of velocity. The body flap schedule has not been fine tuned but should be adequate for purposes of this memorandum. Figures 5 thru 11 present pertinent trajectory parameters such as heating rate, velocity, altitude, dynamic pressure, flight path angle, drag acceleration, and load factor. Figures 12 thru 15 present time histories of the temperatures of the four control points, nose, wing leading edge, elevon, and body flap. Figures 16 thru 18 present hinge moment values for the body flap and elevon and indicate that the maximum values are well within the design limits.

5.0 Conclusions

The data presented provide the necessary information for preliminary analysis of OFT Mission #1. Results of preliminary trajectories of Missions 2 through 6, when merged with these data, should adequately define the need for additional and/or revised requirements necessary for most systems and subsystems of the vehicle. Undoubtedly, certain trajectory changes will also result and these will be included in the subsequent 6 DOF simulations from entry interface through touchdown.

6.0 References

A) Master Flight Test Assignments Document JSC-07700-10-MVP-01 Vol. X

B) Shuttle Orbital Flight Test Requirements JSC-08576 January 15, 1975

C) A Compilation of Ground Tracks of Various Circular and Elliptical Orbits NASA General Working Paper No. 10,009 August 16, 1963

D) TPS Simplified ModelRRockwell Internaltion Memorandum #RI-SEH-ITA-74-197 Dated December 11, 1974

E) TPS Entry Design Trajectory Number 14414.1 Rockwell Internaltional Letter No. 393-150-174-113 Dated December 11, 1974

TABLE I

BASIC REQUIREMENTS

		MFTAD REQUIREMENT	PRELIMINARY TRAJECTORY
Inclination (Orbital)	Deg.	$\simeq$ 35	32.689
Altitude (Orbital)	N.M.	$\leq$ 150	120
Duration (Orbital)	Orbits	3	3
Payload Weight	Pounds	$\leq$ 10 K	10 K
Center of Gravity	%	66.25	66.25
Cross Range	N.M.	$\leq$ 200	138
Heat Rate	$Btu/Ft^2/sec$	Low	69.8
Heat Load	Btu/Ft^2	Low	50800
Landing Site		Edwards	Edwards

TABLE II

INITIAL CONDITIONS

(Orbital Insertion)		
Latitude	Deg.	30.430825
Longitude	Deg.	-72.507631
Altitude	N.M.	120
Velocity (Inertial)	Ft/sec	25506
Azimuth (Inertial)	Deg.	77.488646
(De-orbit-Hohmann)		
Time (from insertion)	Sec.	1403.5 (in Rev. #3)
Latitude	Deg.	-27.88
Longitude	Deg.	107.71
ΔV	Ft/sec	250.00
(Entry Interface)		
Latitude	Deg.	10.051081
Longitude	Deg.	172.43697
Altitude	Ft.	400000
Velocity (Inertial)	Ft/sec	25634.84
Azimuth (Inertial)	Deg.	58.85309
Flight Path Angle (Inertial)	Deg.	-1.0947
Range to Target	N.M.	4100
Latitude Target	Deg.	34.905
Longitude Target	Deg.	-117.8827
Total Weight	#	165000
C.G. Location	%	66.25
Total Cross Range	N.M.	138

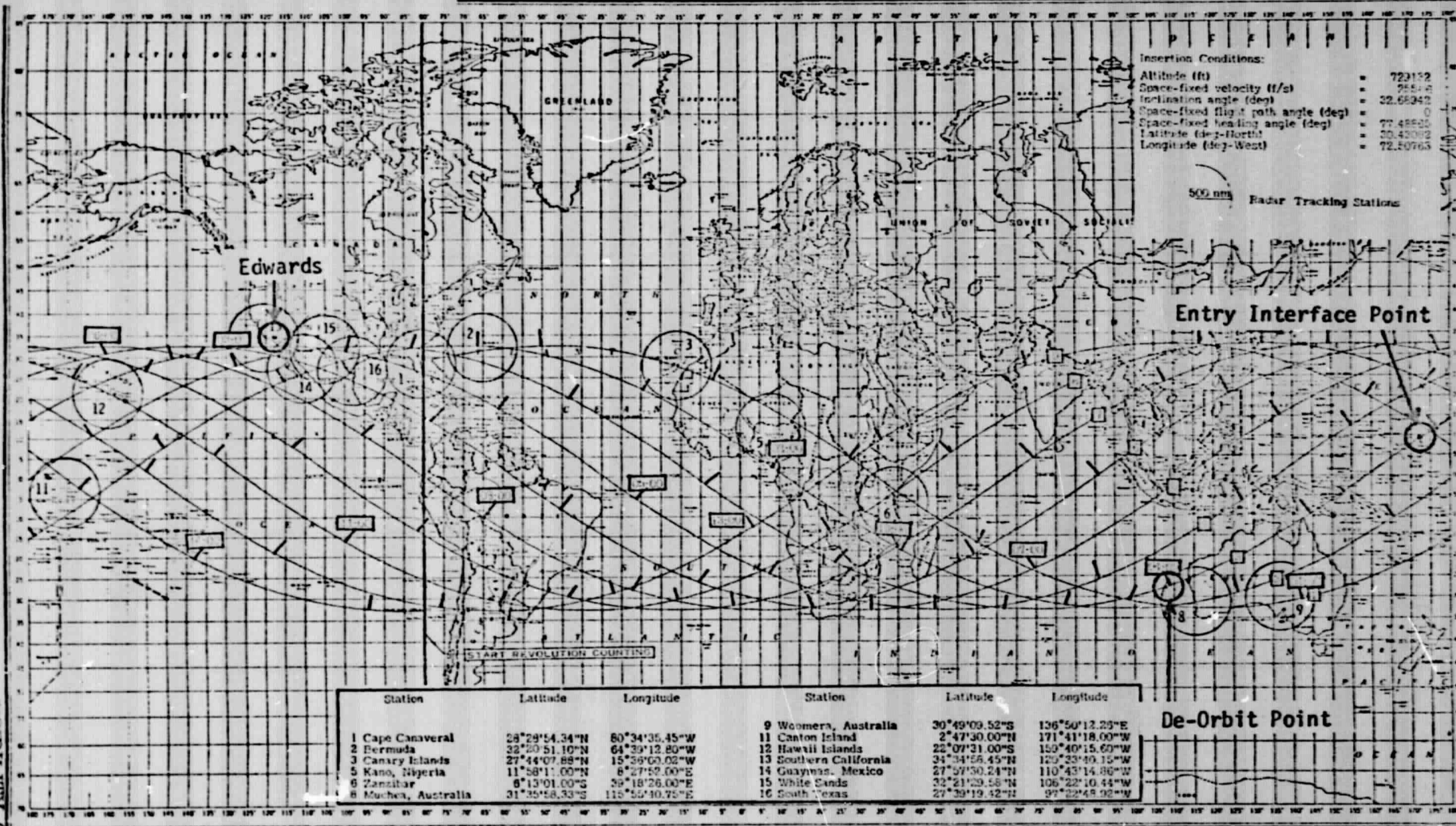
Note: Geodetic Coordinates

TABLE III

MAJOR PARAMETER SUMMARY TABLE

PARAMETER	OFT #1	BASELINE 14414.1
MAX $\dot{q}$ BTU/FT^2/SEC	69.8	79.5
$\int \dot{q}dt$ BTU/FT^2	50805	62547
T_{max} (BODY FLAP) DEG.	2181	2725
T_{max} (ELEVON) DEG.	2229	2530
TAEM INTERCEPT RANGE N.M.	30.8	N/A
TAEM INTERCEPT VELOCITY FT/SEC	1505	1500
TAEM INTERCEPT ALTITUDE FT.	70085	69000
TAEM TIME (SEC)	1606	1620
$N_{G_{max}}$ (V > 6000 FPS)	1.33	1.49
$N_{G_{max}}$ (V < 6000 FPS)	1.32	1.56

PRELIMINARY TRAJECTORY FOR FIRST OFT



Station	Latitude	Longitude	Station	Latitude	Longitude
			9 Woomera, Australia	30°49'09.52"S	136°50'12.26"E
1 Cape Canaveral	28°29'54.34"N	80°34'35.45"W	11 Canton Island	2°47'30.00"N	171°41'18.00"W
2 Bermuda	32°20'51.10"N	64°39'12.80"W	12 Hawaii Islands	22°07'31.00"S	159°40'15.60"W
3 Canary Islands	27°44'07.88"N	15°36'00.02"W	13 Southern California	34°34'56.45"N	120°33'40.15"W
5 Kano, Nigeria	11°58'11.00"N	8°27'52.00"E	14 Guaymas, Mexico	27°57'30.24"N	110°43'14.86"W
6 Zanzibar	6°13'01.00"S	39°18'26.00"E	15 White Sands	32°21'29.58"N	106°22'10.44"W
8 Muchea, Australia	31°35'58.33"S	115°55'40.75"E	16 South Texas	27°39'19.42"N	97°22'48.92"W

Fig. 1 Orbital Flight Path

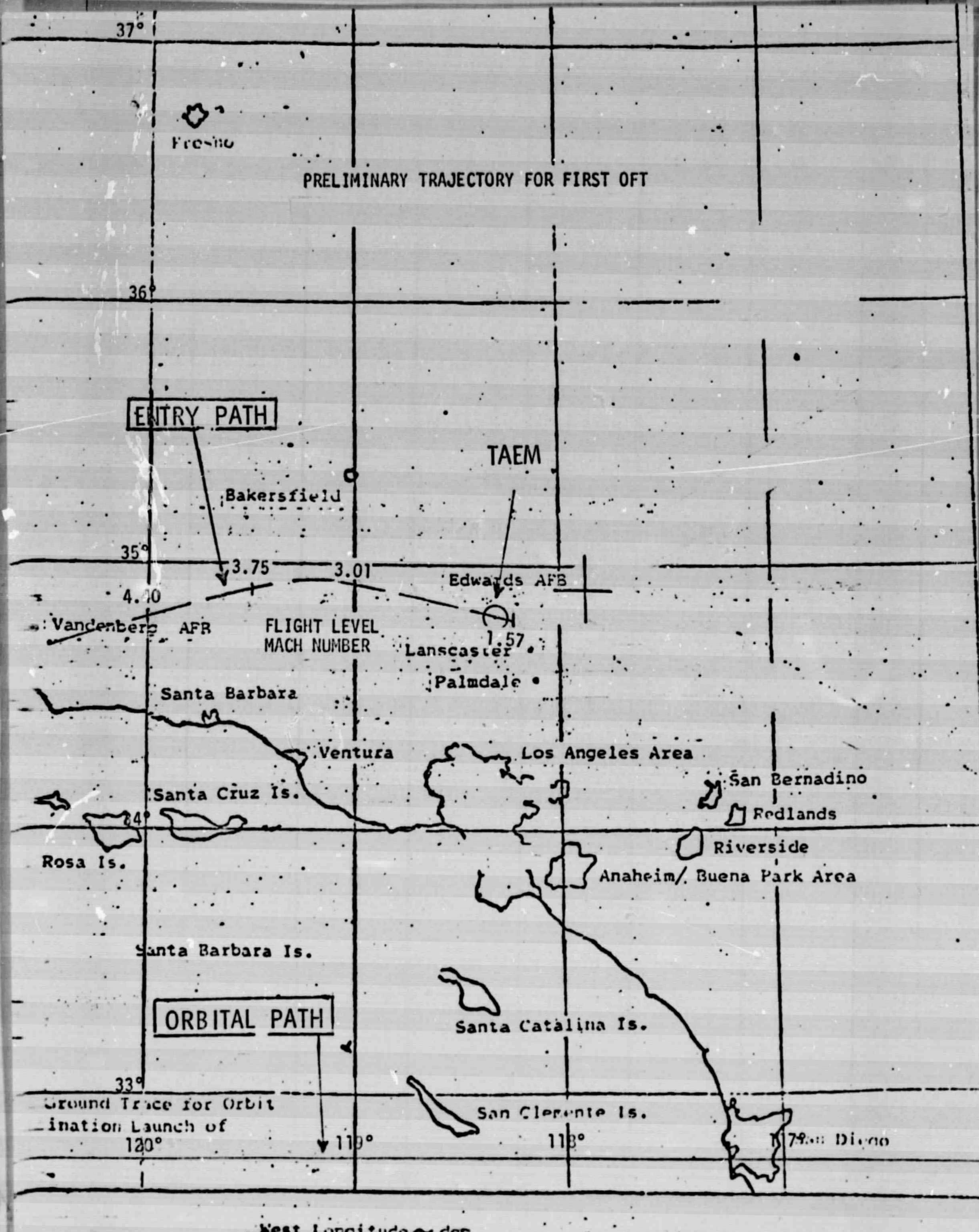


Fig. 2 Final Flight Path

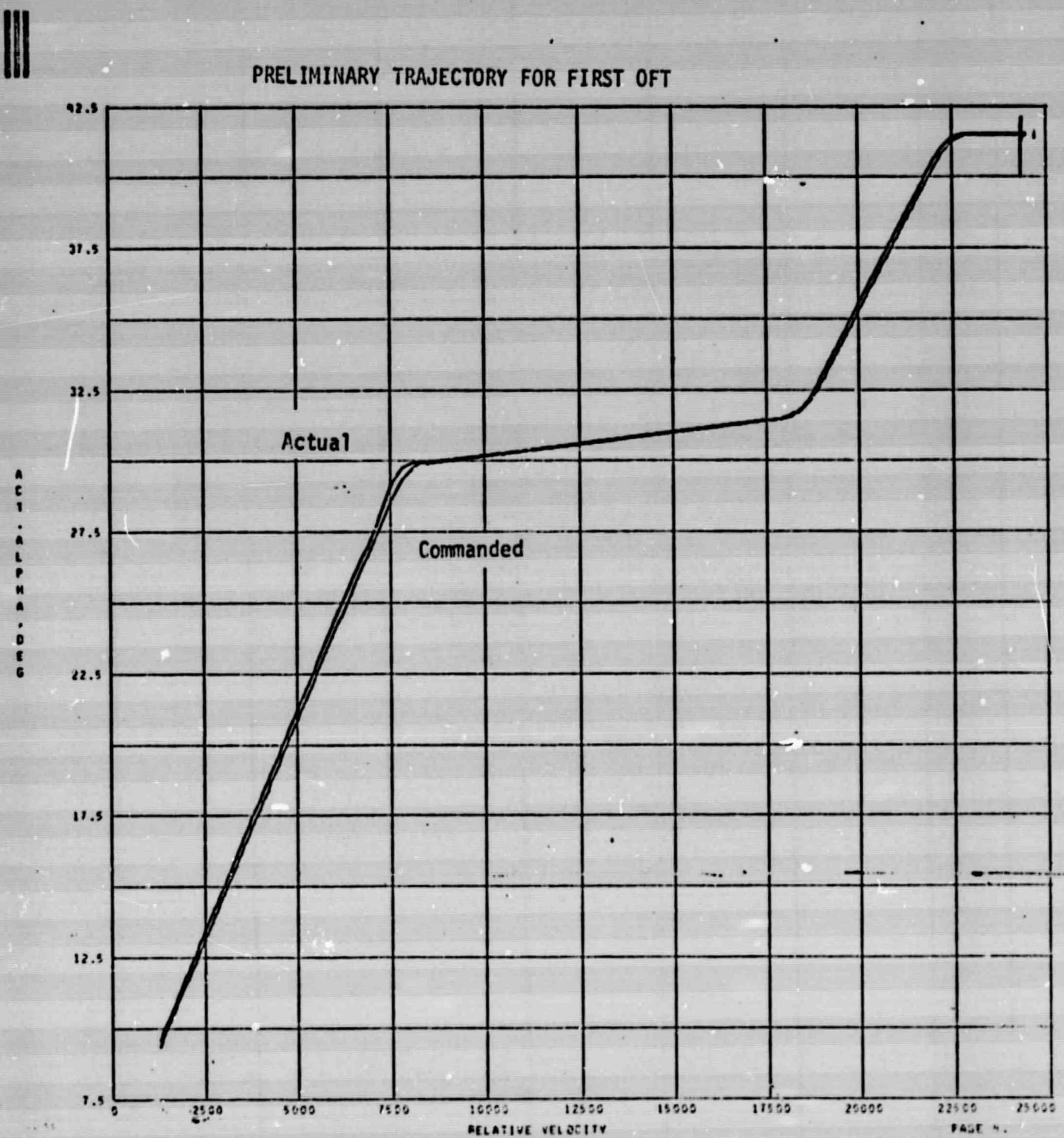


Fig. 3 Angle of Attack Versus Relative Velocity

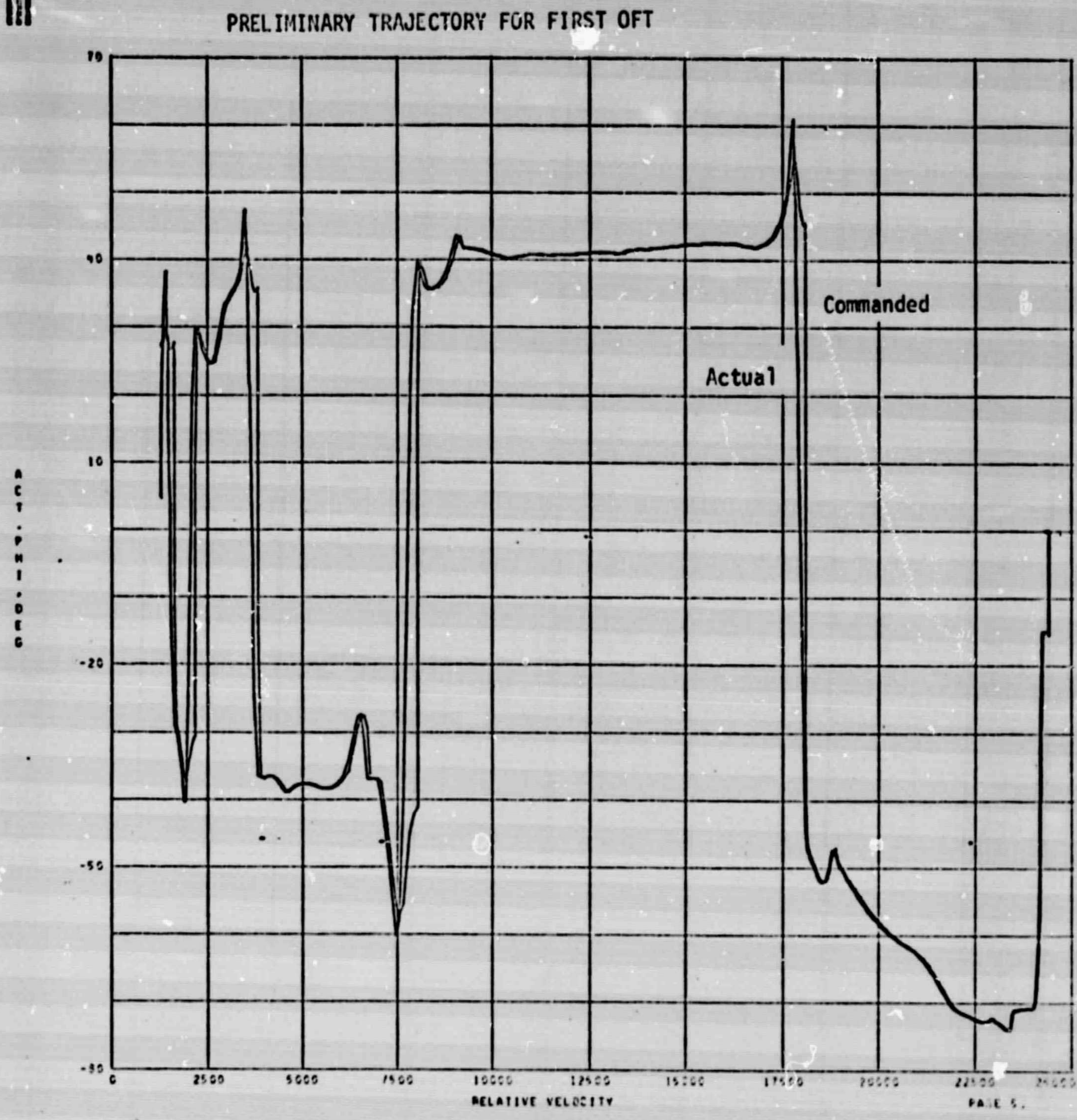


Fig. 4 Bank Angle Versus Relative Velocity

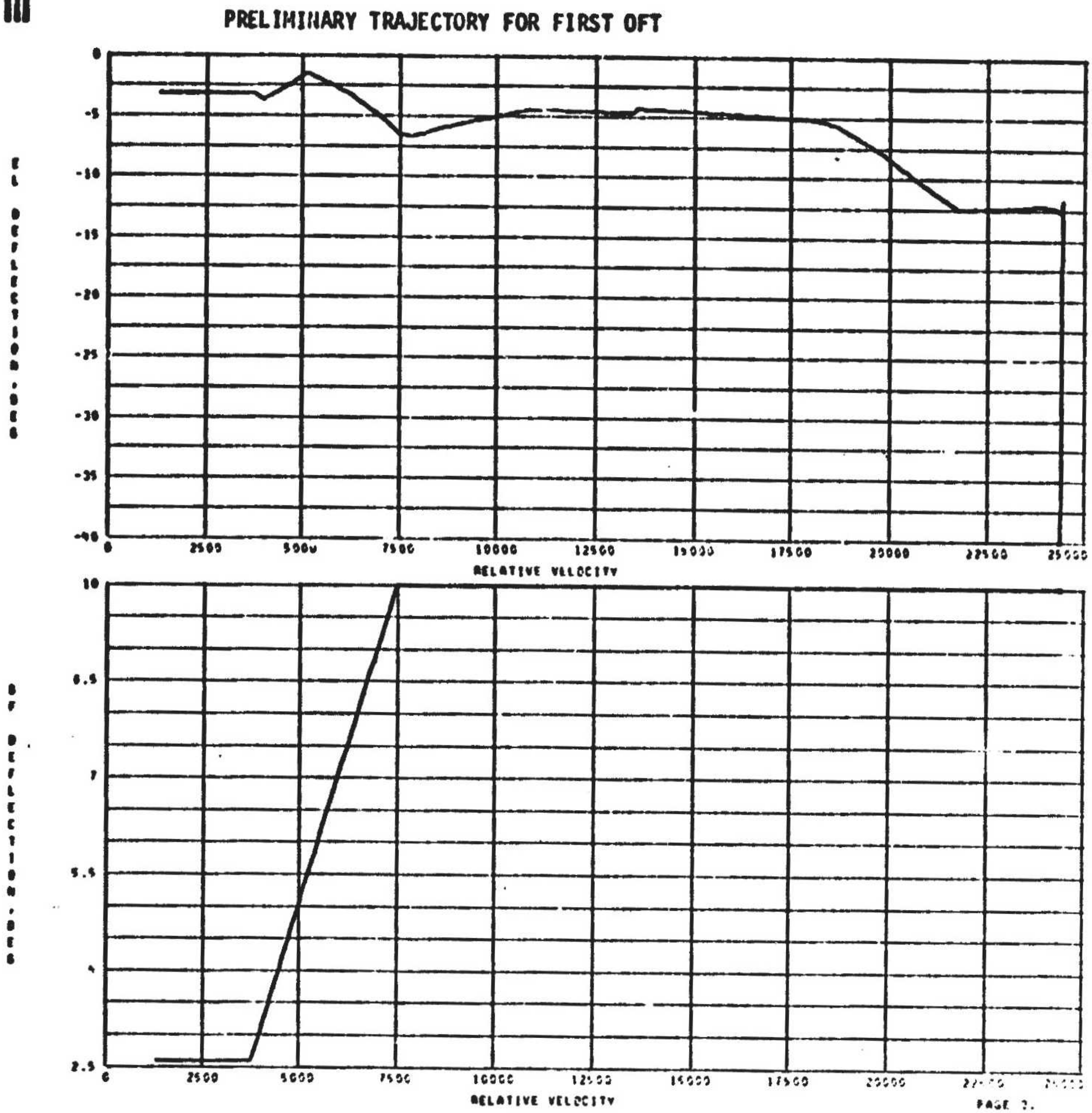


Fig. 5 Elevon and Body Flap Deflection Versus Relative Velocity

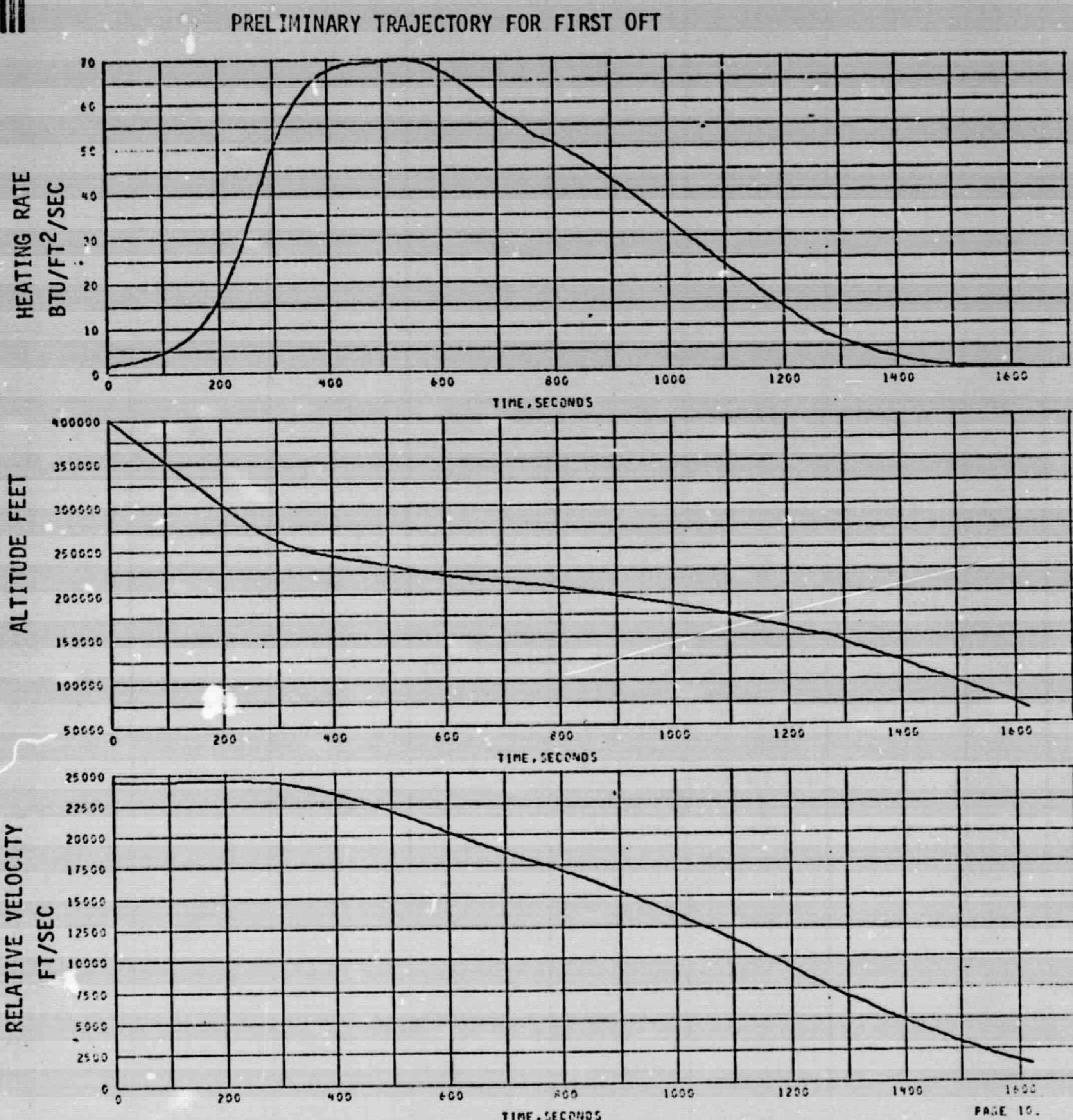


Fig. 6 Heating Rate, Altitude and Relative Velocity Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

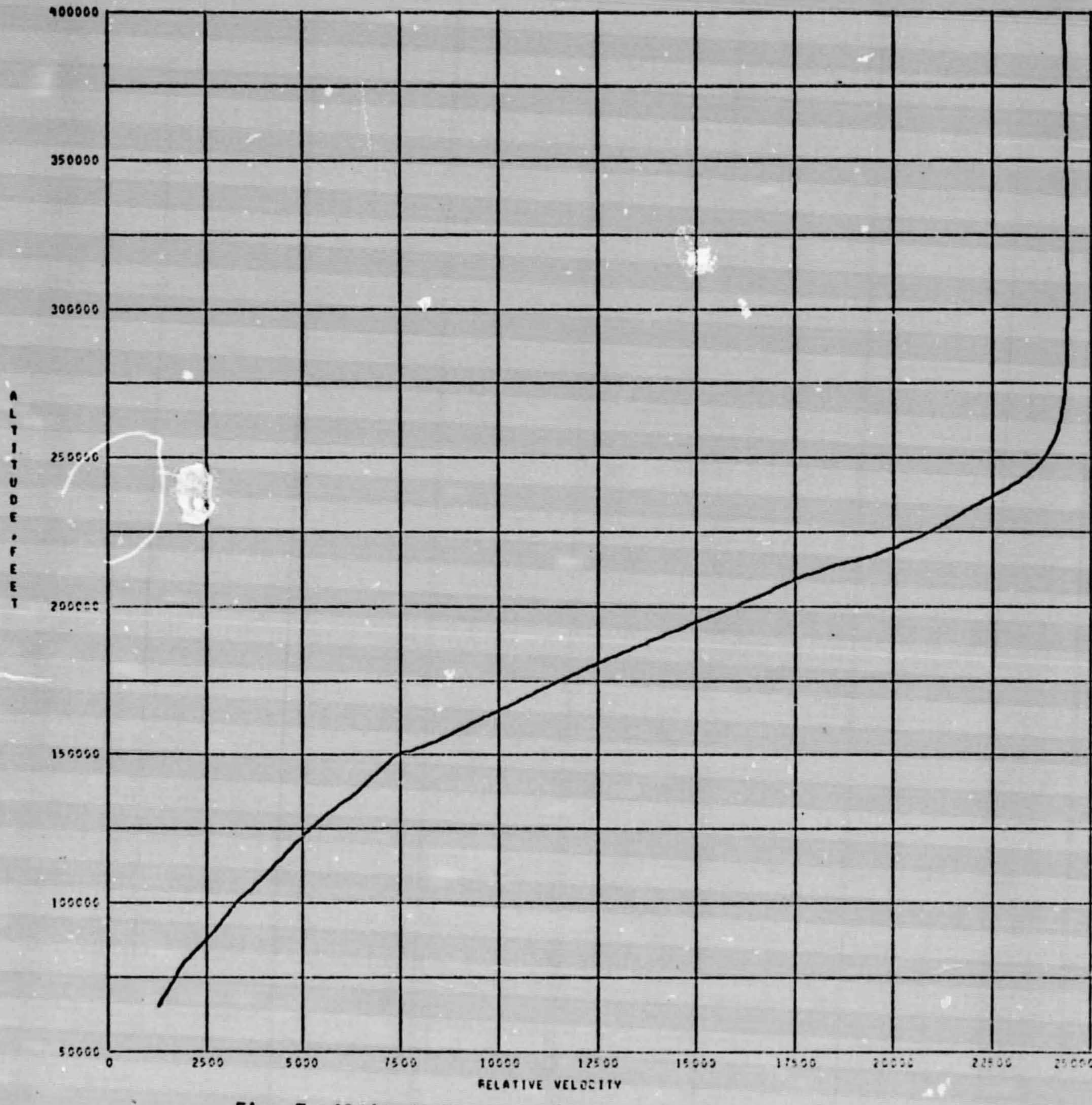


Fig. 7 Altitude Versus Relative Velocity

PRELIMINARY TRAJECTORY FOR FIRST OFT

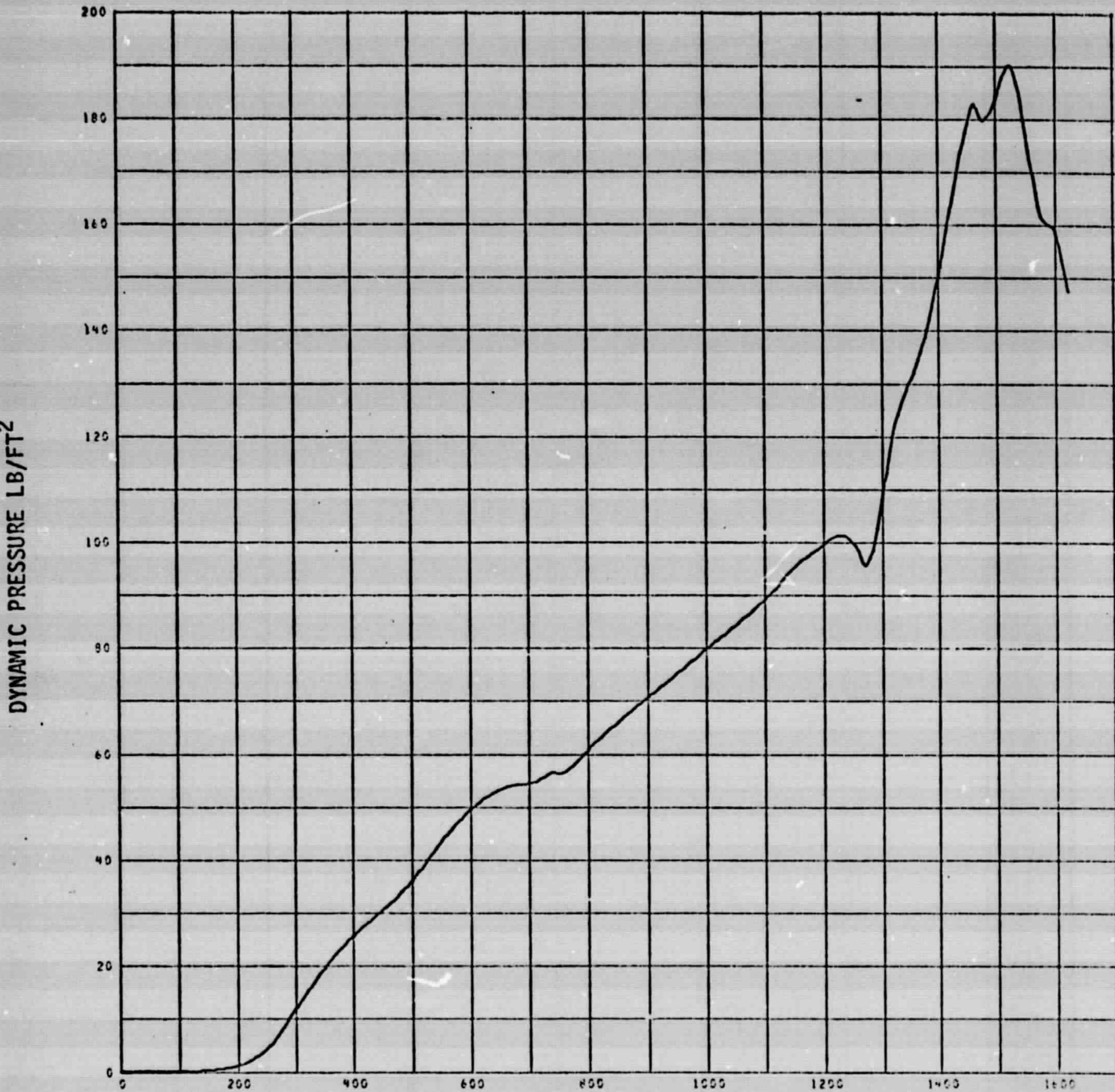


Fig. 8 Dynamic Pressure Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

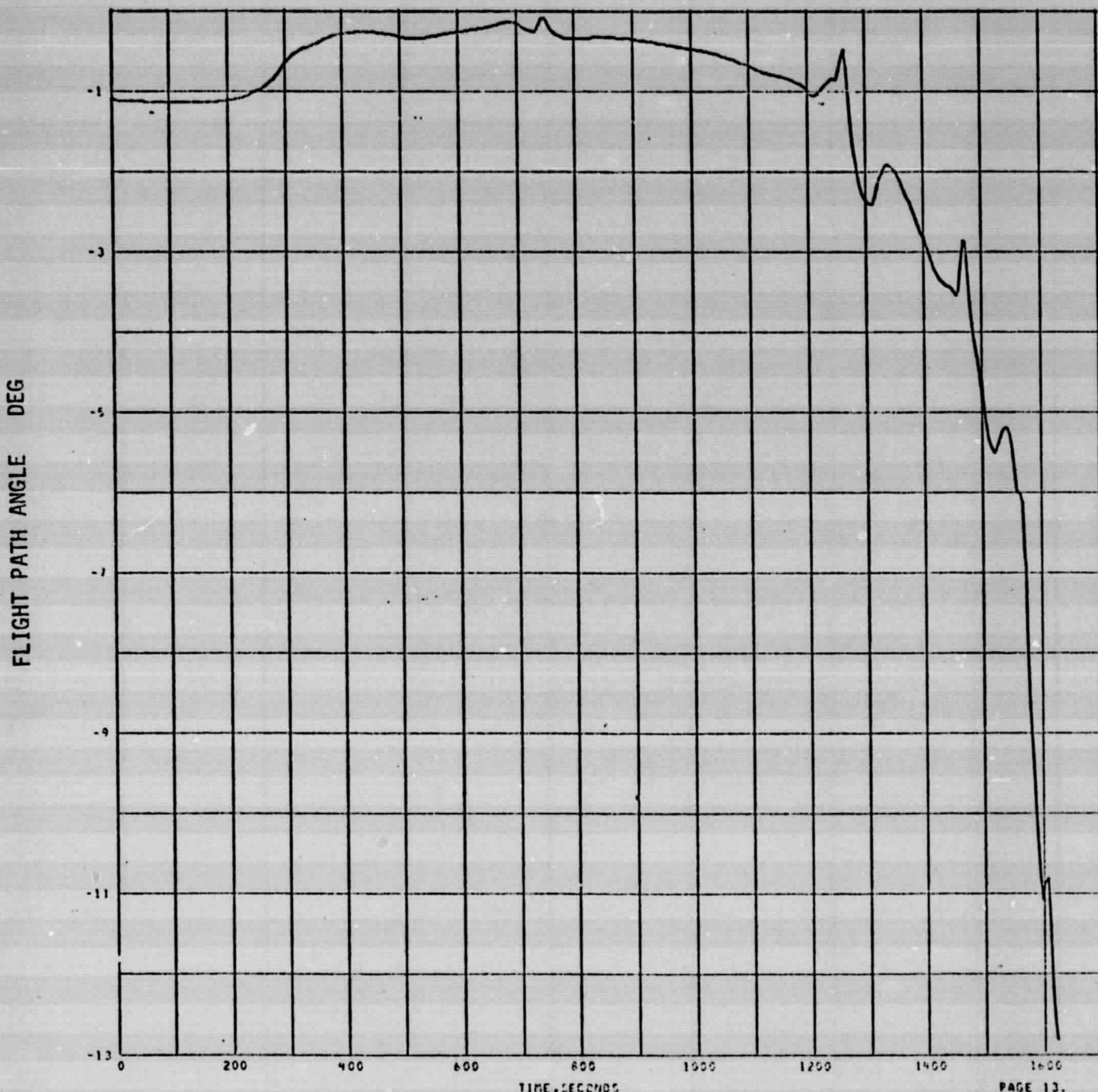


Fig. 9 Flight Path Angle Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

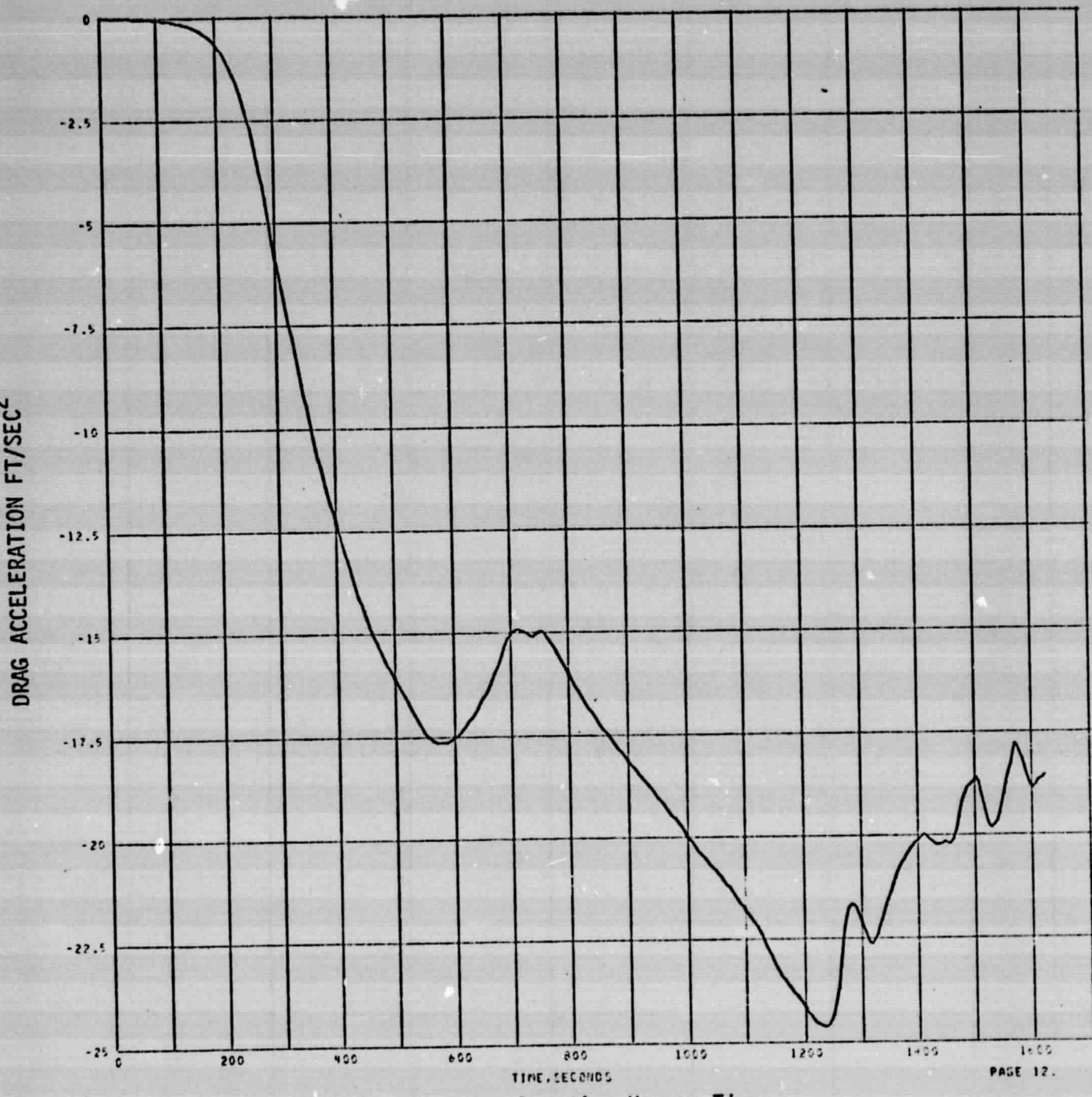


Figure Fig. 10 Drag Acceleration Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

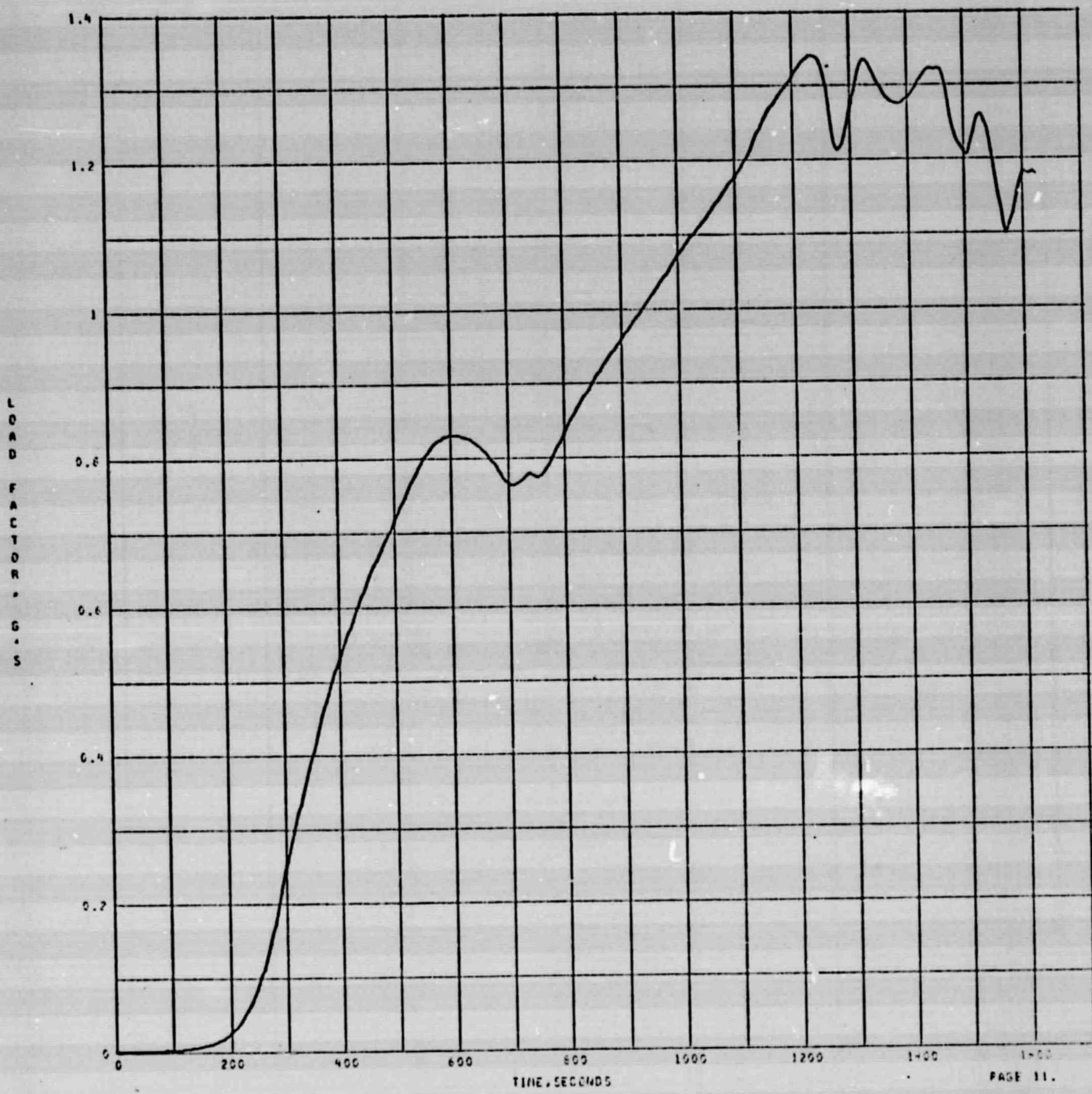


Fig. 11 Load Factor Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

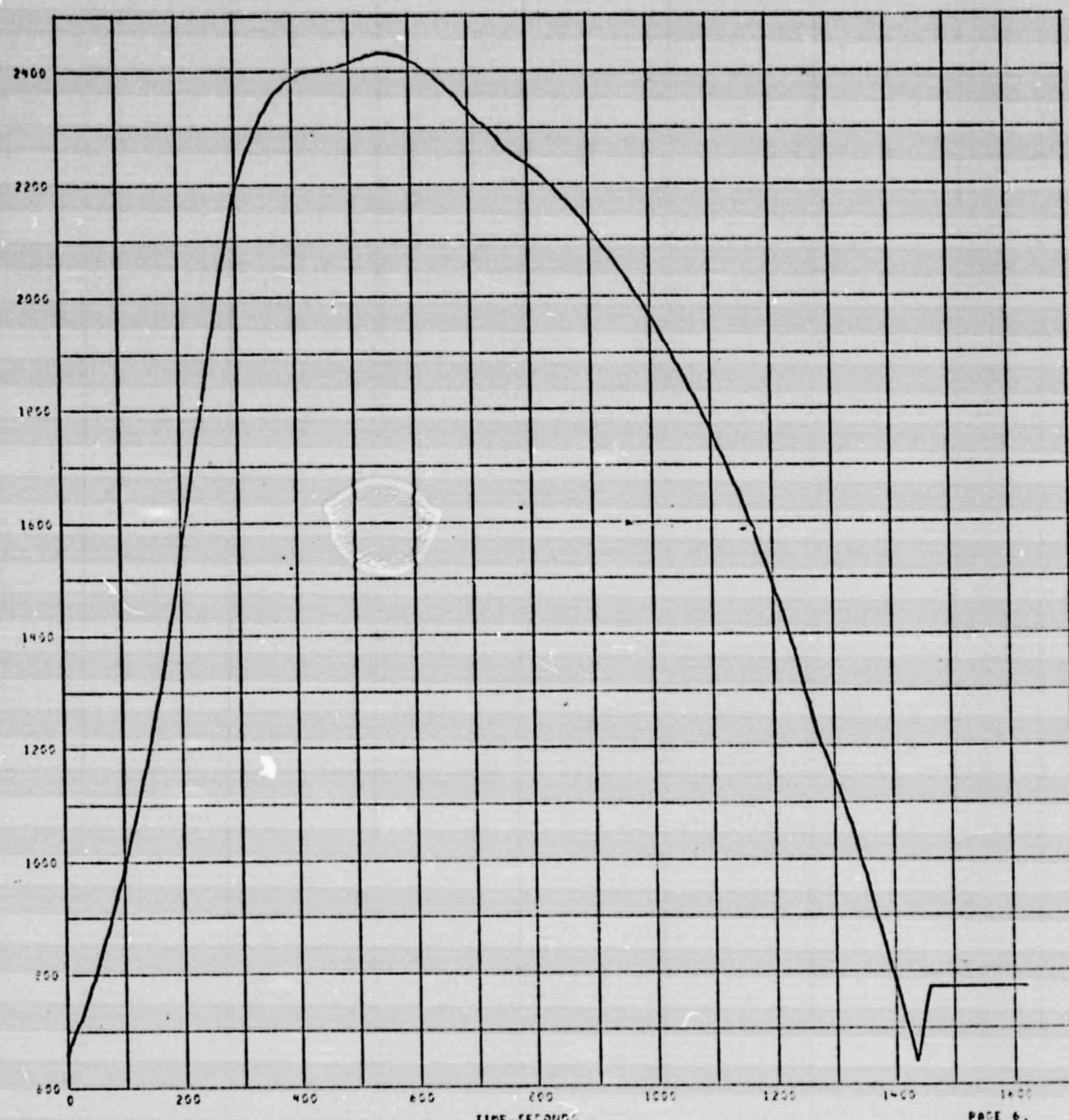


Fig. 12 Nose Temperature Versus Time

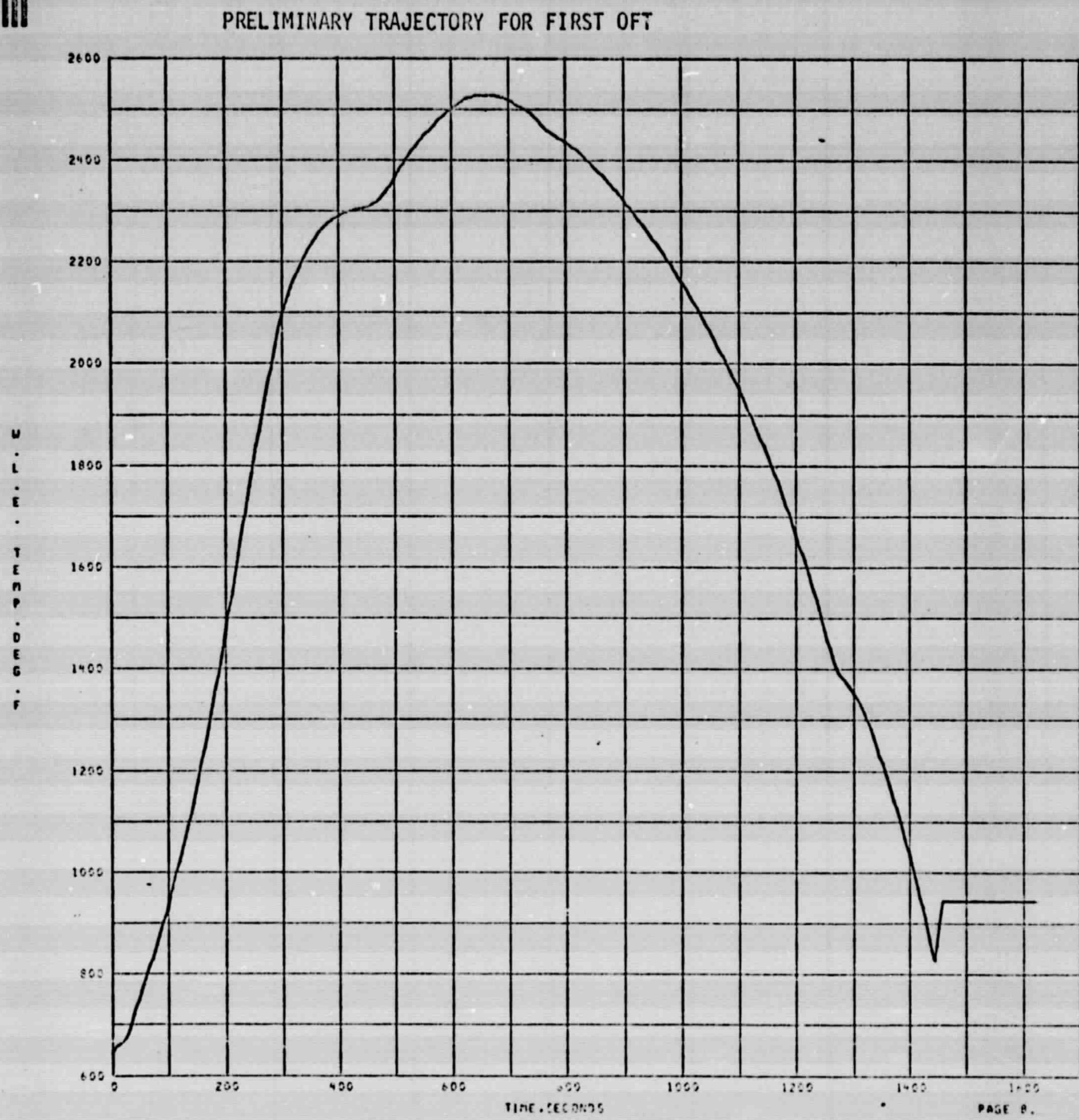


Fig. 13 Wing Leading Edge Temperature Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

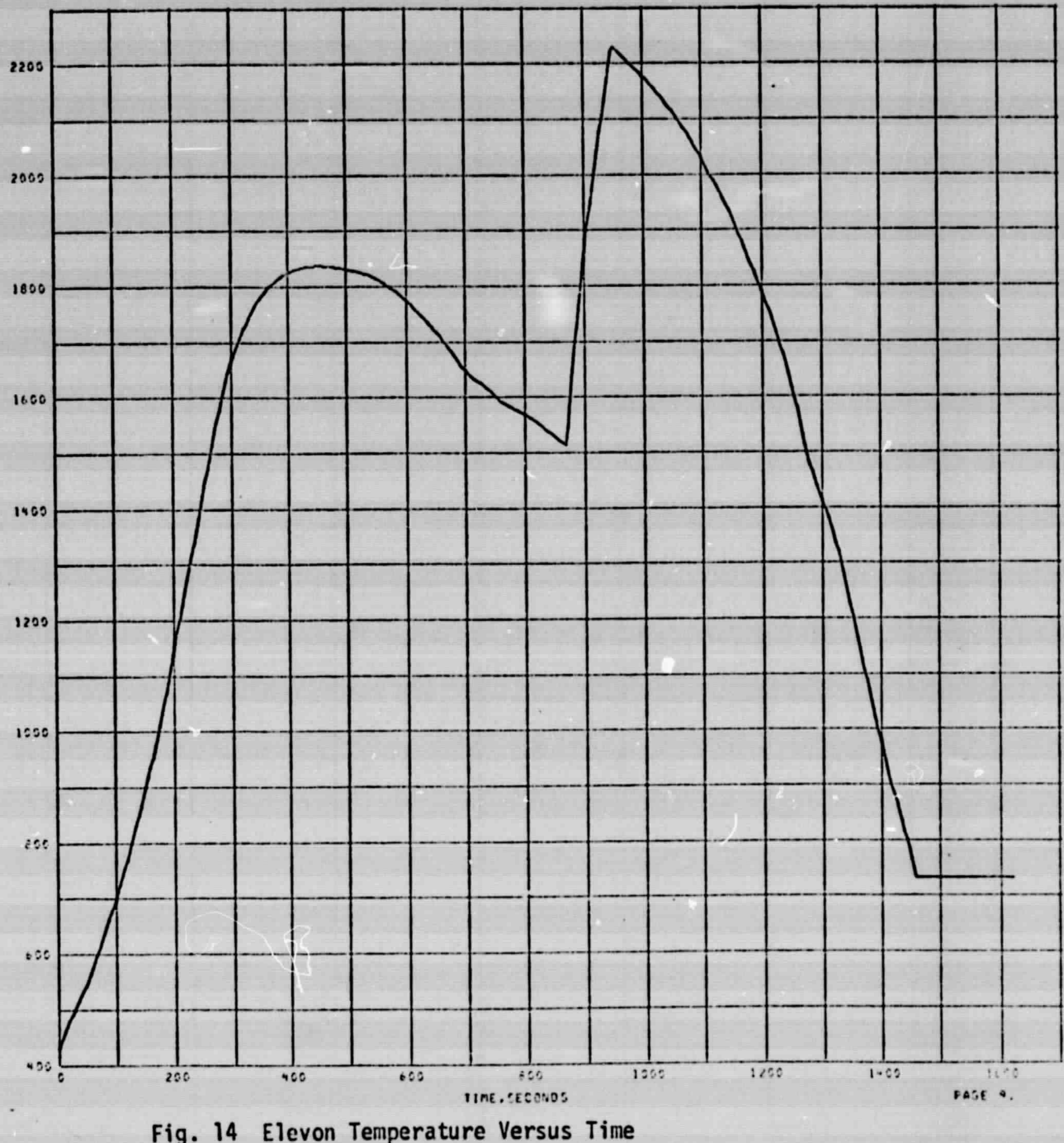


Fig. 14 Elevon Temperature Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

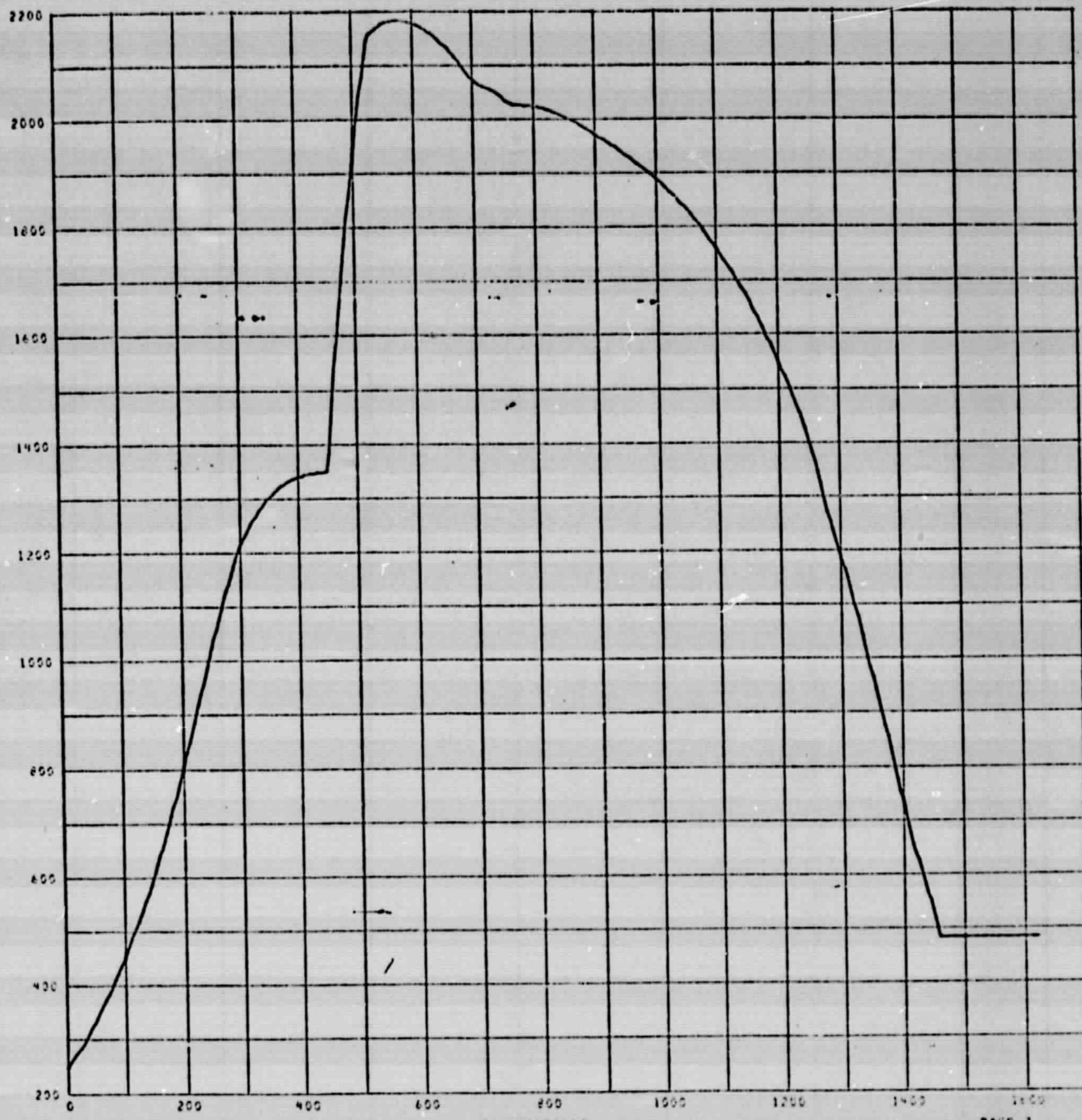


Fig. 15 Body Flap Temperature Versus Time

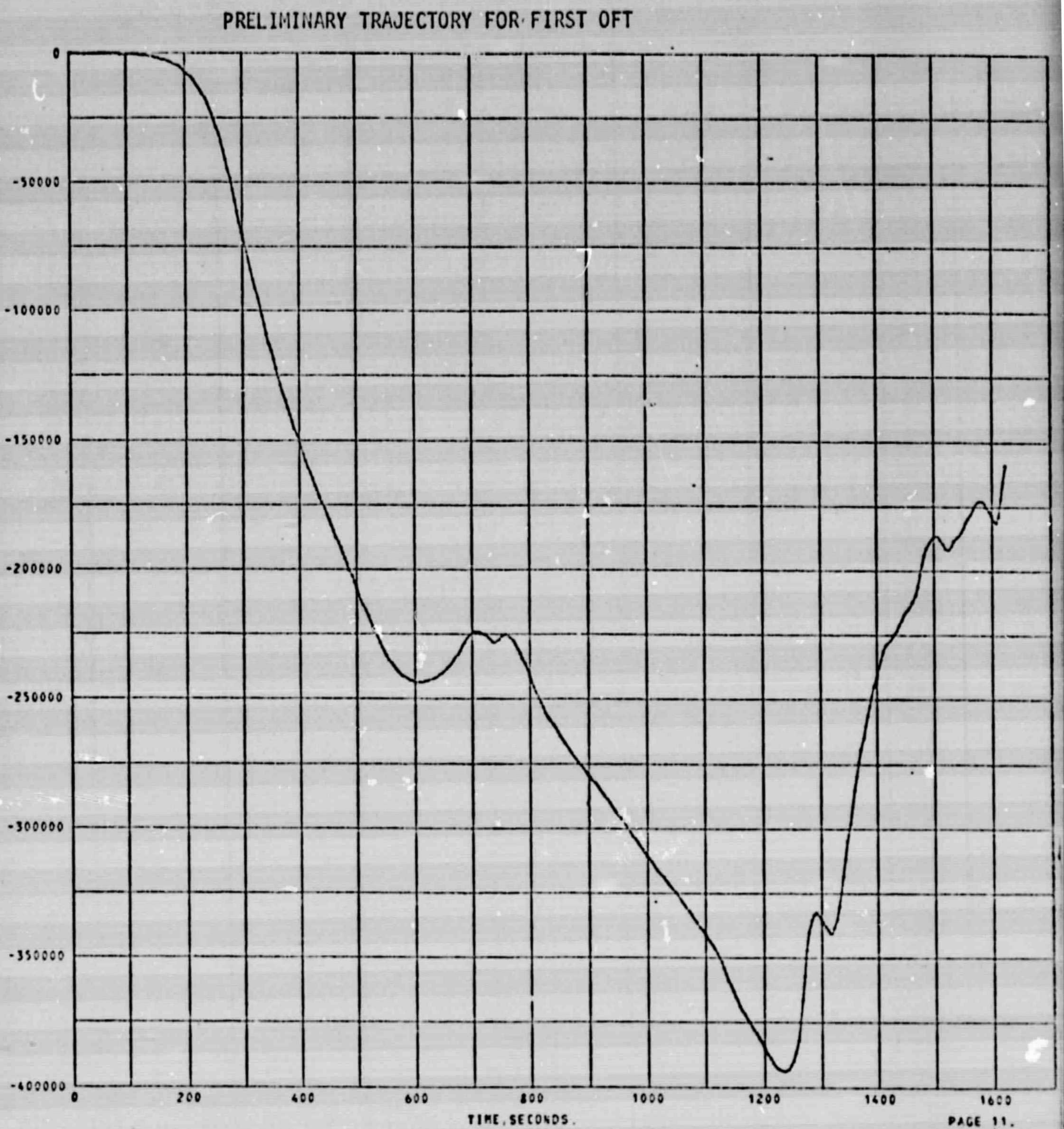


Fig. 16 Body Flap Hinge Moment Versus Time

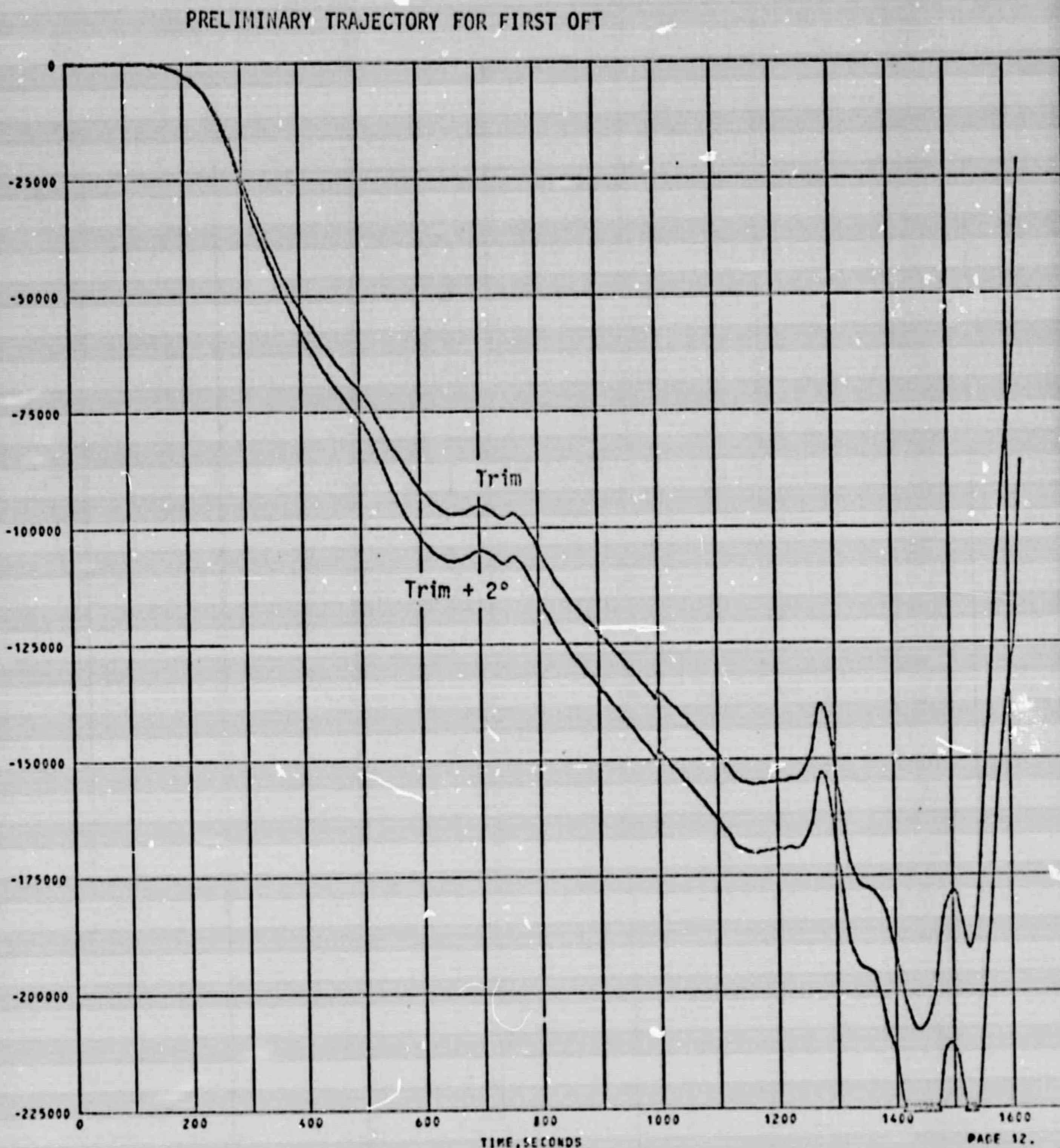


Fig. 17 Inboard Elevon Hinge Moment Versus Time

PRELIMINARY TRAJECTORY FOR FIRST OFT

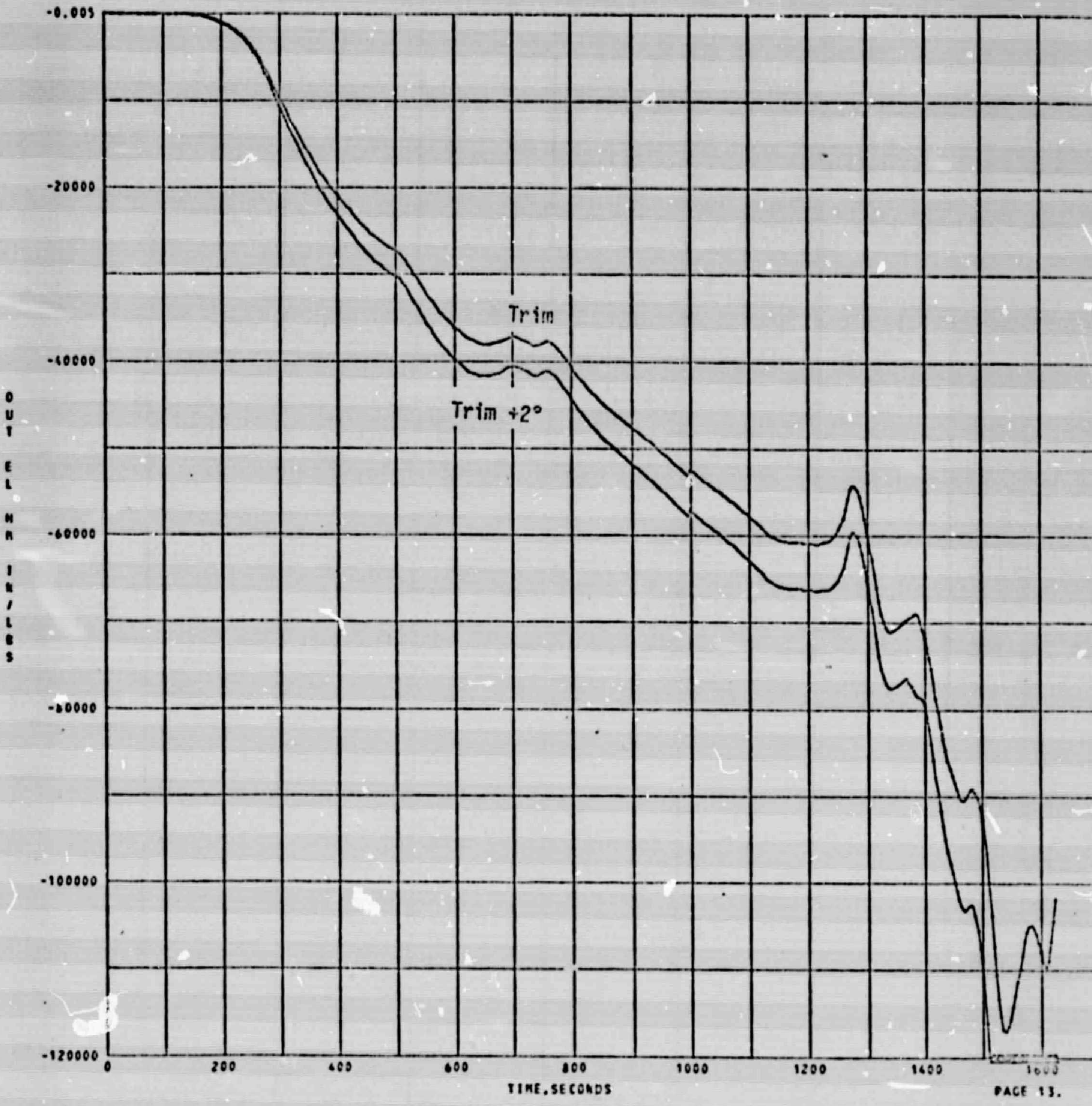


Fig. 18 Outboard Elevon Hinge Moment Versus Time